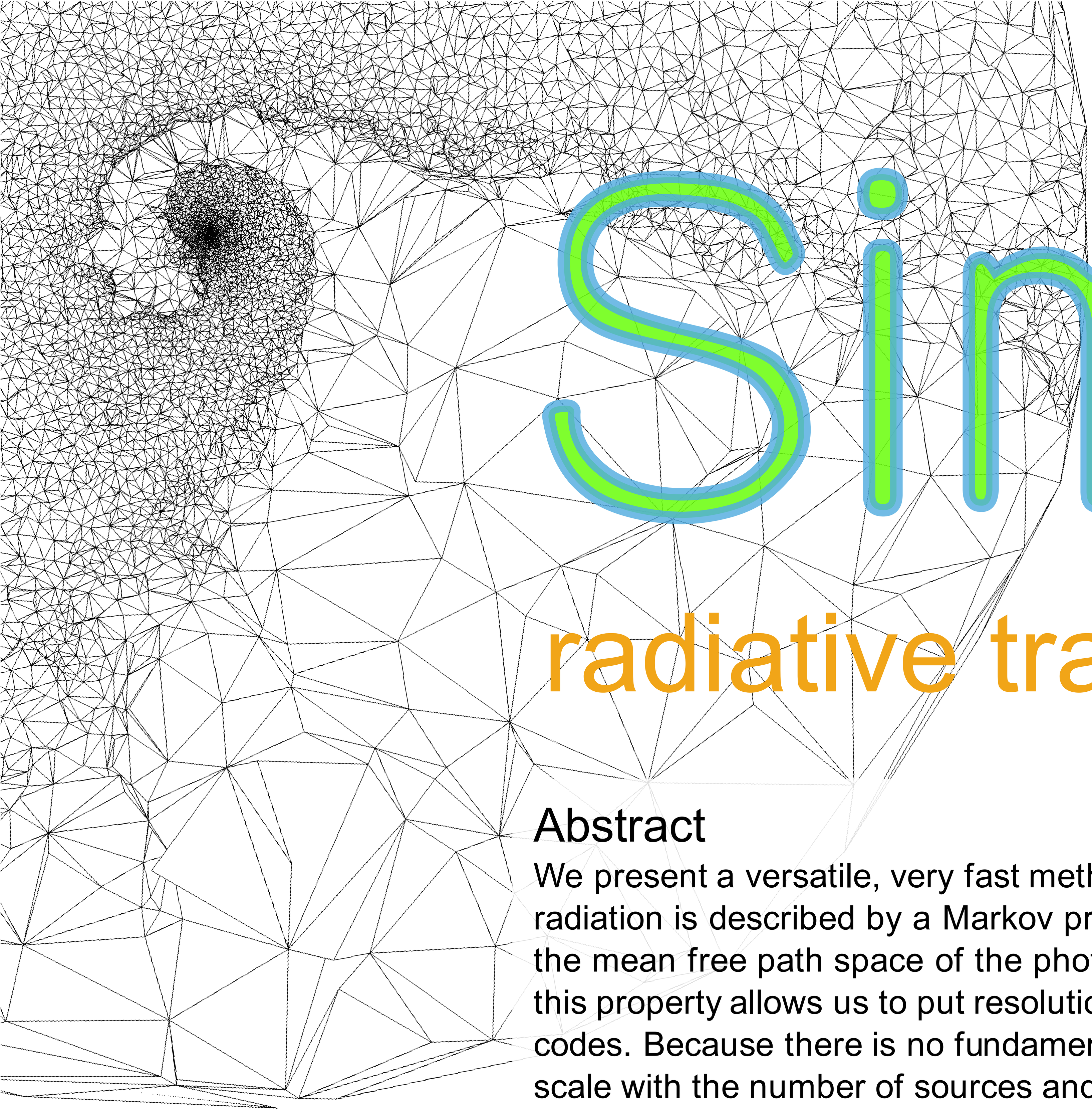

SimpleX

radiative transfer on unstructured grids

Abstract

We present a versatile, very fast method designed for radiative transfer in a variety of astrophysical problems. The transport of radiation is described by a Markov process on an irregular grid. We have shown that the grid can be constructed to represent the mean free path space of the photons meaning that the length scales of the grid itself are very physical indeed. Moreover, this property allows us to put resolution where it is needed very similar to adaptively refined meshes applied in hydrodynamical codes. Because there is no fundamental difference between a source and a scattering/absorbing particle our method does not scale with the number of sources and treats diffuse photons without computational overhead.

The Grid

In our method, particles (e.g. photons) are transported between nodes of an unstructured grid. This grid is constructed to describe the properties of the underlying physical medium. We sample a given medium (a density- or optical depth field) with a Poisson point process and use the resulting point distribution to tessellate space according to the Voronoi recipe: all points in a cell are closer to the nucleus of that cell than to any other nucleus. The Voronoi nuclei are connected by a Delaunay triangulation as shown in Figure 1.

Radiative Transfer

In one computational cycle, every nucleus in our grid transports its content to neighbouring nuclei, optionally absorbing or adding particles. Which neighbours are selected for transport depends on the process: In the case of diffuse (re-)emission, particles are transported to all neighbours (see left panel of Figure 2) and in case of ionization or ballistic transport only to the most straightforward neighbours (see right panel of Figure 2).

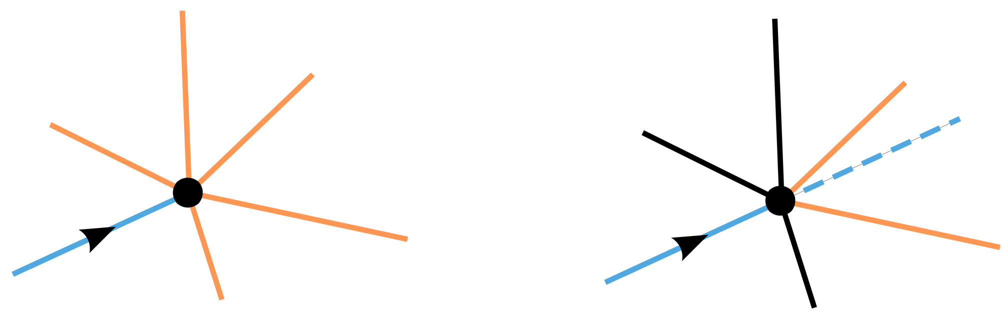

Figure 2
Left panel: diffuse transport: Incoming photons (blue) are transported to all neighbours (orange). Right panel: ballistic transport: Incoming photons are distributed over the most straightforward lines only (orange). Two in 2D and three in 3D.

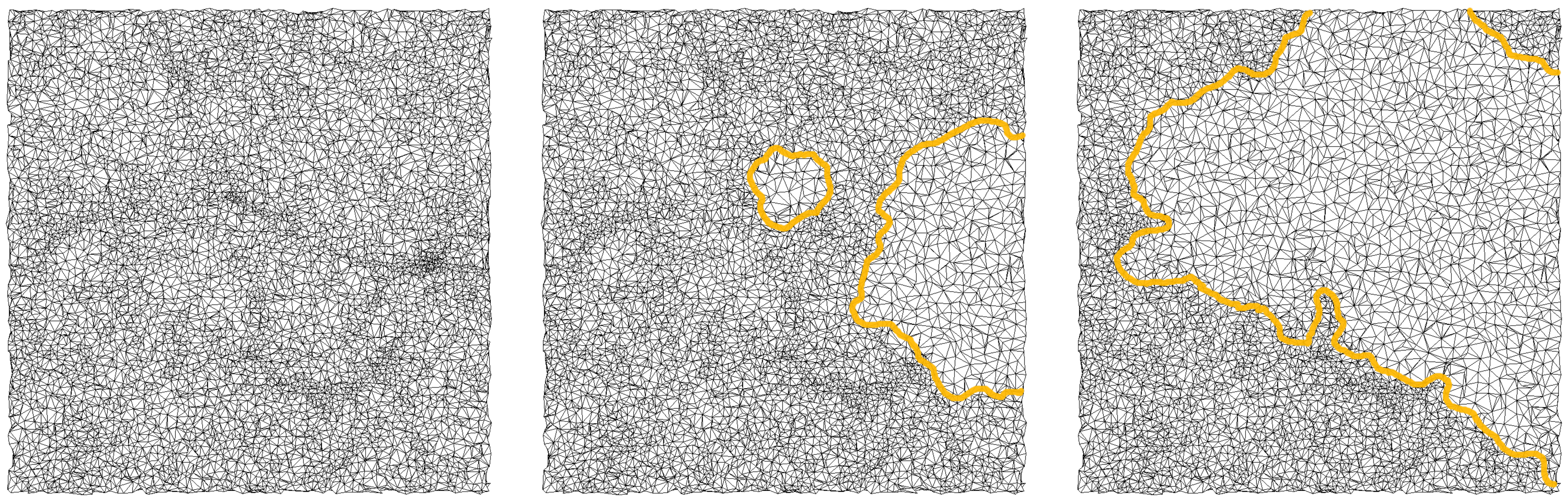

Figure 3.
Dynamical Delaunay grid based on a cosmological density field of 0.5 Mpc across. The grid is de-refined behind the ionisation front (orange line) according to the increased optical mean free path of the photons. In this way, the typical travel distance of a photon from one interaction to the next scales with its mean free path at all times. Updating the grid dynamically increases accuracy as well as computational speed.

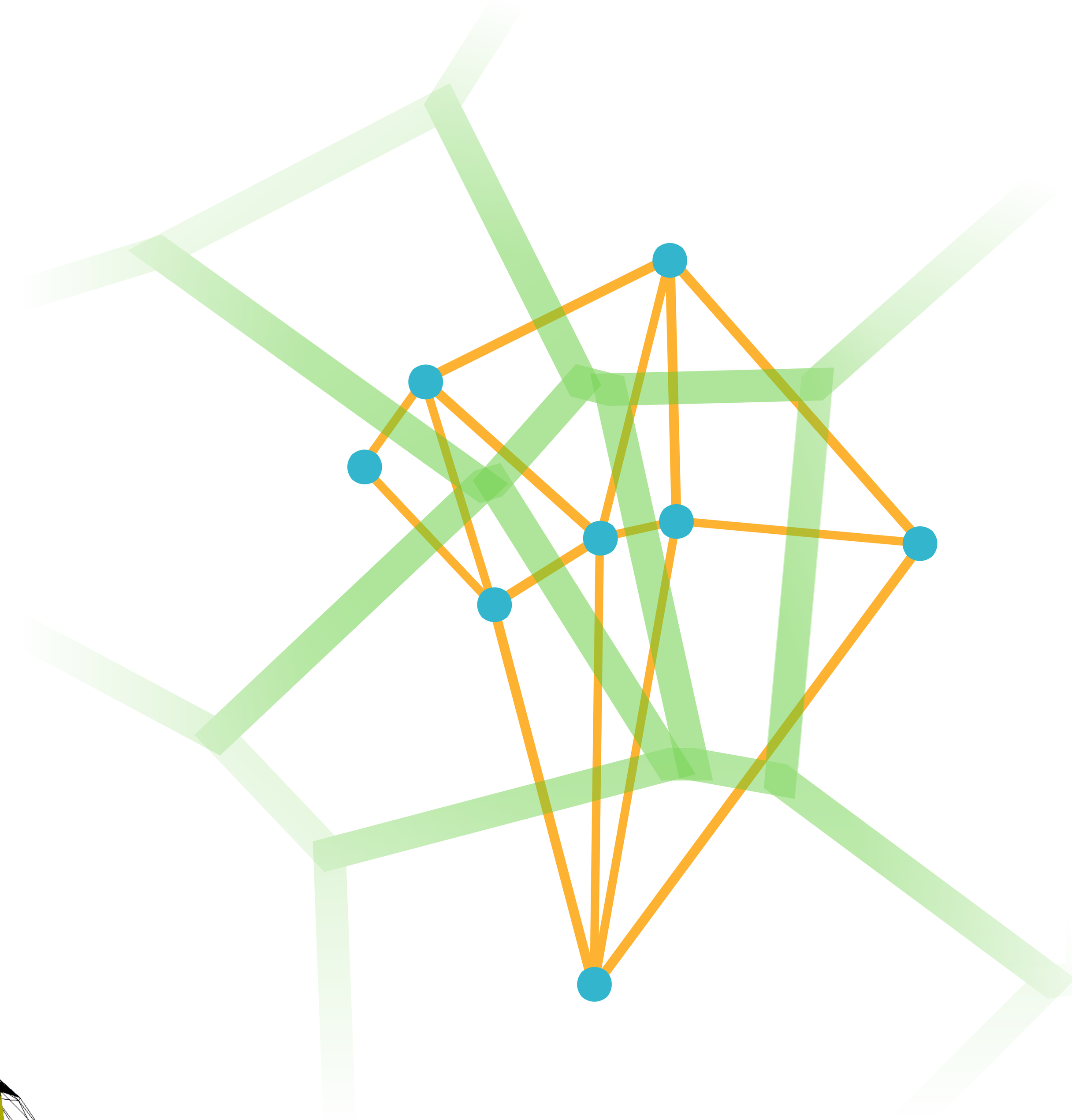

Figure 1.
Some nuclei of Voronoi cells (turquoise) and their Delaunay connections (orange). Only adjacent cells are connected.

SimpleX

Our method is implemented in a C++ package called SimpleX [1]. A parallel version is being coupled to the Flash hydro-code [2] facilitating fully coupled radiation hydrodynamics on an adaptively refined grid. By dynamically updating our triangulation, we are able to correctly account for changes in the optical depth at chemical timescales. As SimpleX is particle based in nature, integrating it in SPH(-type) methods is relatively straightforward. SimpleX is being used to study the epoch of re-ionization [1,3] (see Figure 3) and the formation of the first stars. We aim at applications in the field of atmospheres of massive stars in the near future (see Figure 4).

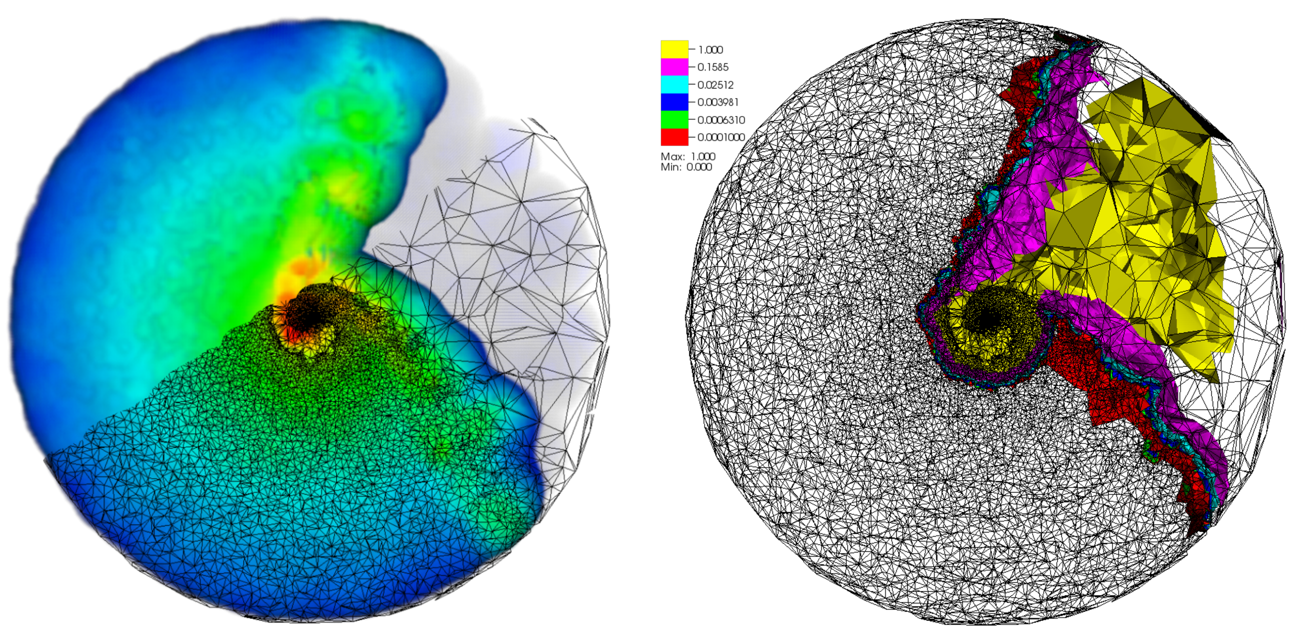

Figure 4.
Left panel: Density field (red is high, blue is low density) obtained from an SPH simulation of interacting stellar winds by [4]. Overlayed is a Delaunay grid based on the density field. Cell sizes range over 5 orders of magnitude. Right panel: Contours of the ionized fraction of the gas. The optically thin inner part (corresponding to the large cells) is almost completely ionised while the bulk of the gas (left hemisphere) is effectively shielded from the ionising star and consequently remains neutral.

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[2] Fryxell, B. et al. 2000 ApJS, 131, 273F
[3] Ritzerveld, J. 2007 PhD Thesis
[4] Okazaki et al. 2008 MNRAS, 388, L39-L43

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